Using IXO to Probe
The Nature of Pulsar Winds

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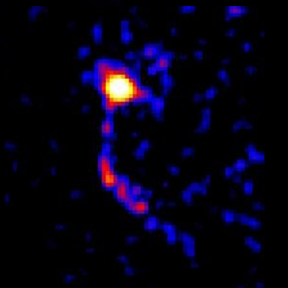
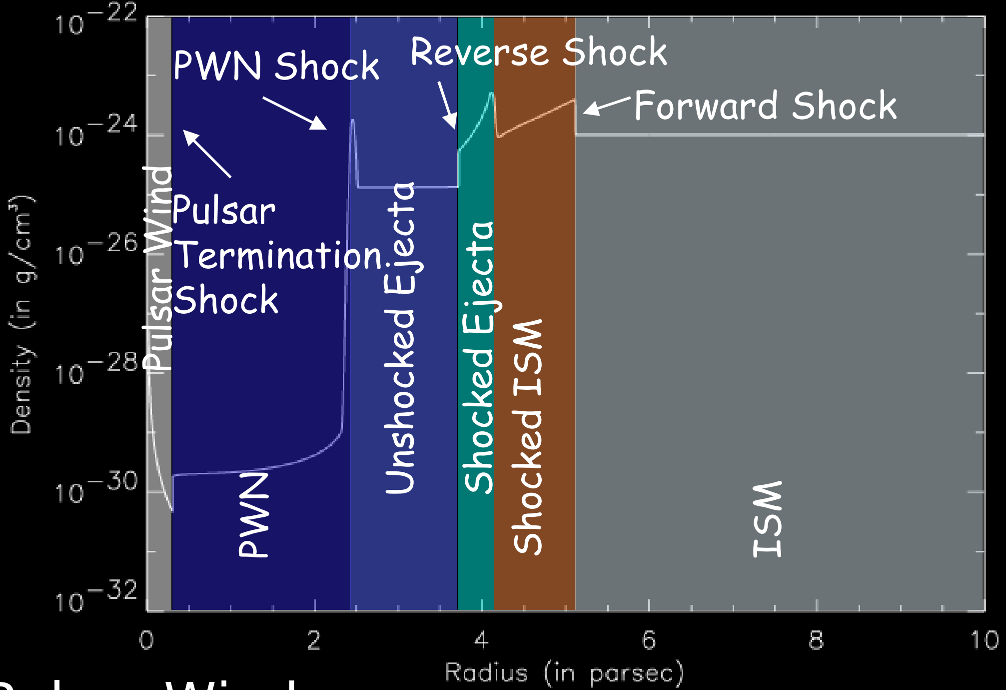
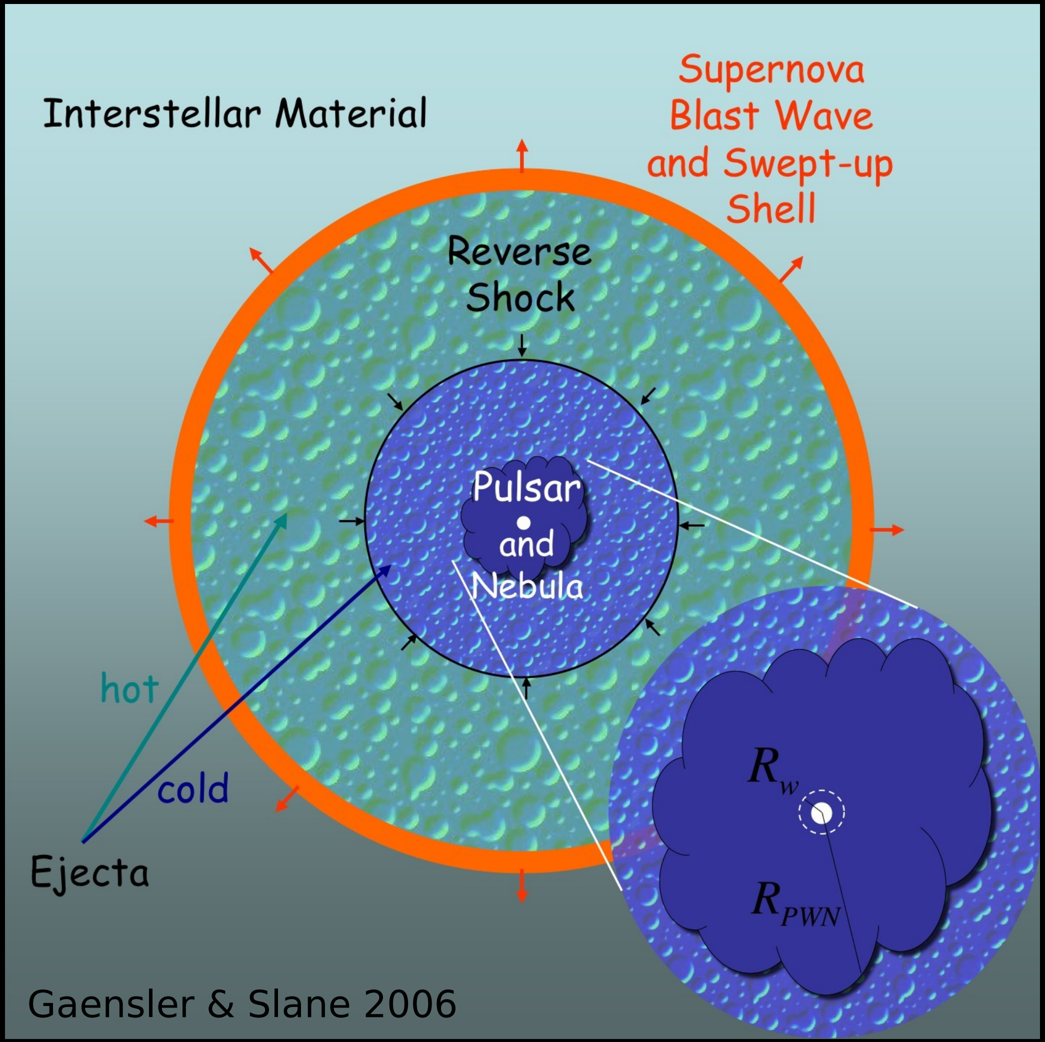
Key Science Points



- PWNe are unique laboratories for studying the life cycle of energy
  - Rotational energy is converted into high energy radiation and energetic particles, allowing us to study the properties of:
    - outflows and jets
    - termination shocks
    - acceleration efficiency
  - We know more about the underlying conditions (mass, spin, magnetic field strength and geometry) than for any other systems
- PWNe (and their absence) are signposts for young neutron stars
  - Their properties place constraints on initial spin and magnetic fields
  - What is the full census of PWNe in the Galaxy?
- The evolution of PWNe probes the progenitor structure and environment
  - Shocked ejecta reveals composition; Doppler-broadened lines provide expansion velocities that constrain densities and evolution
  - Nonthermal structure connects emission from radio to TeV bands

PWNe and Their SNRs





Pulsar Wind

- sweeps up ejecta; shock decelerates flow, accelerates particles; PWN forms
- ejecta spectrum constrains expansion velocity and progenitor type/structure

Supernova Remnant

- sweeps up ISM; reverse shock heats ejecta; ultimately compresses PWN; PWN/RS interaction mixes ejecta into relic PWN

PWN Expansion w/ IXO: 3C 58

energy input and swept-up ejecta mass

Measurements of PWN evolution and swept-up mass constrain initial spin and its evolution

PWN evolution

PWN Expansion w/ IXO: 3C 58

- Chandra reveals complex structure of wind shock zone and surroundings
- Spectrum reveals ejecta shell with enhanced Ne and Mg
  - PWN expansion sweeps up and heats cold ejecta

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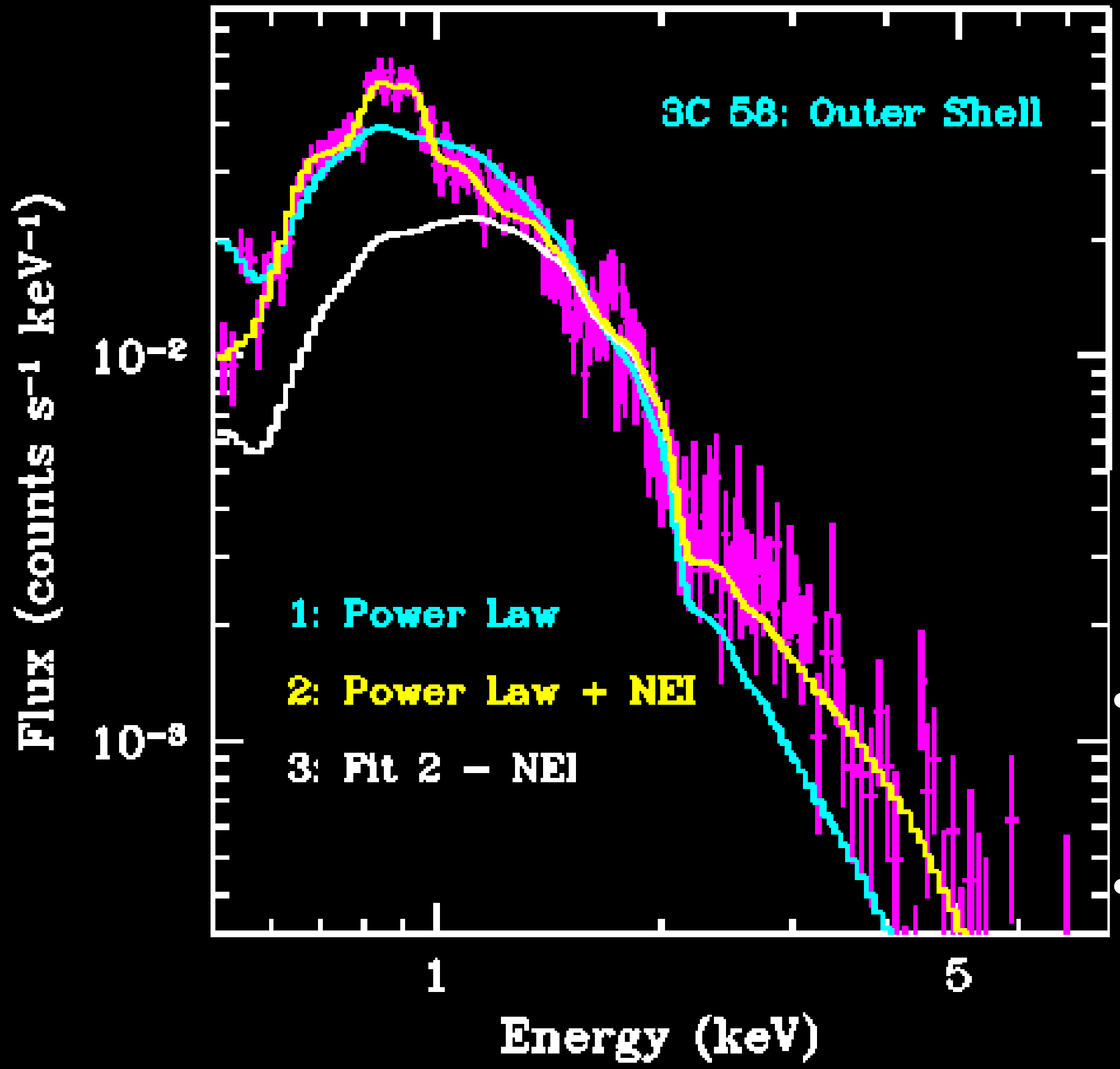

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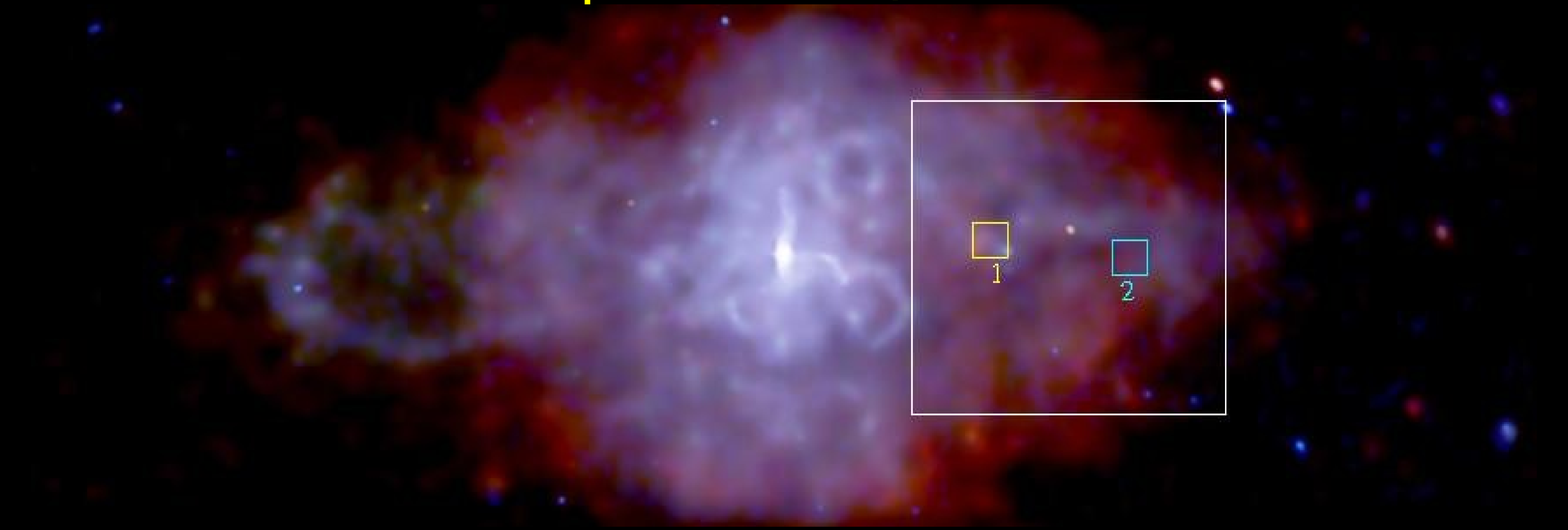
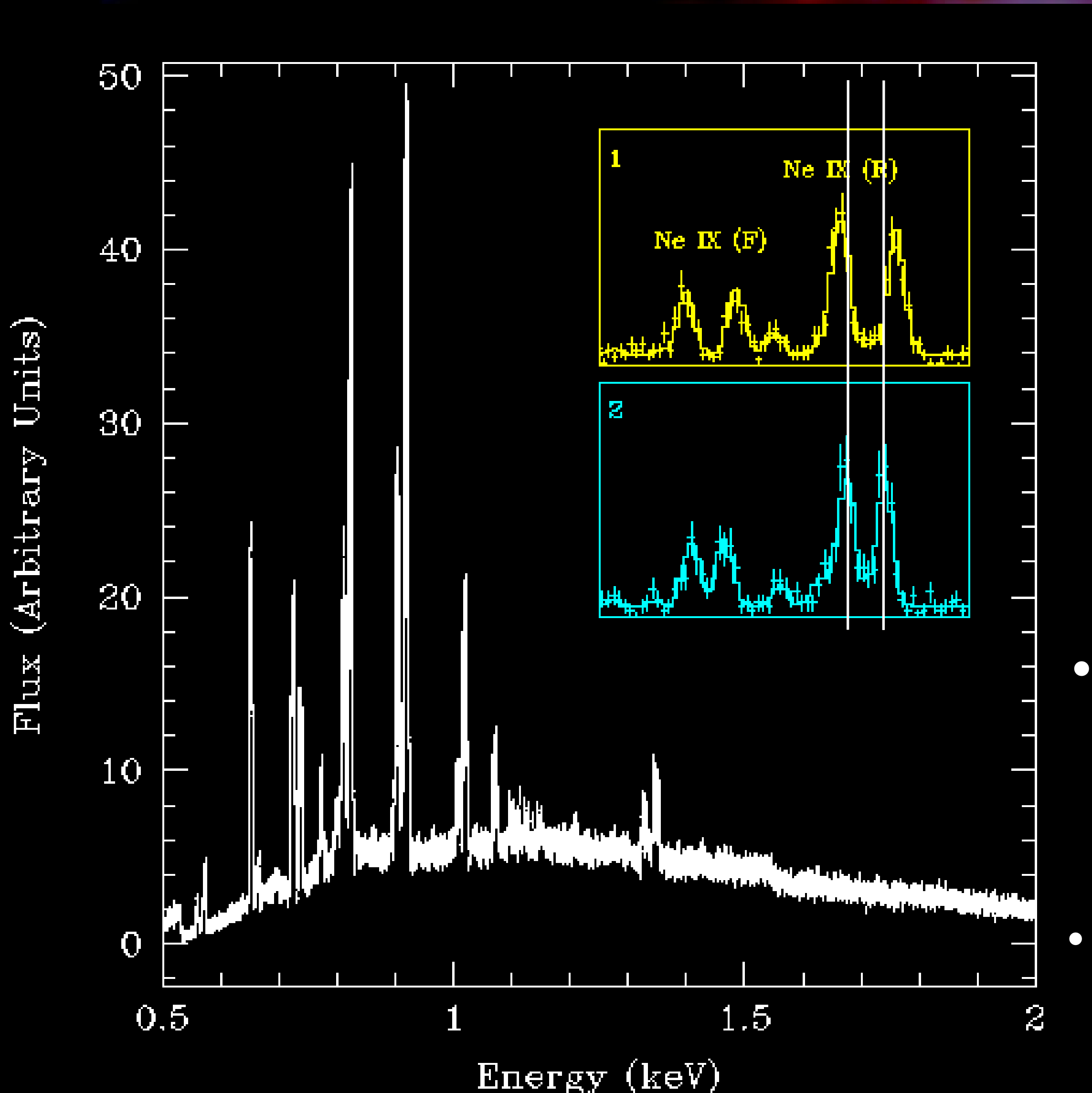
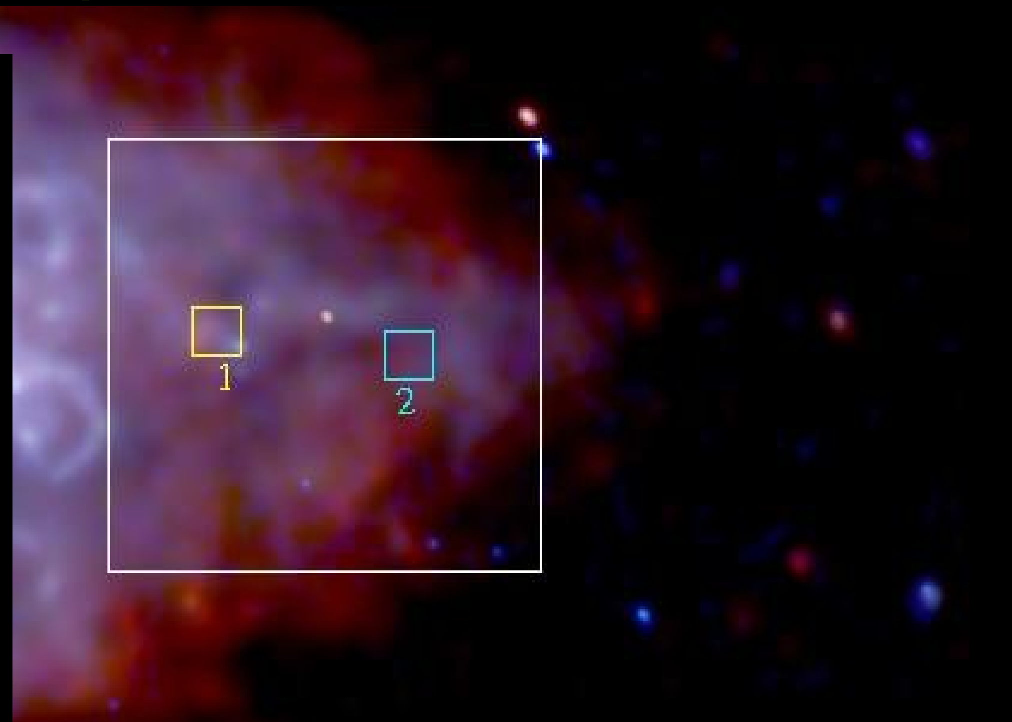


Con-X baseline gives ~16000 counts in Ne line in a 100 ks observation.

- thus, we will get 100 counts from this line in a resolution element 12 arcsec on a side

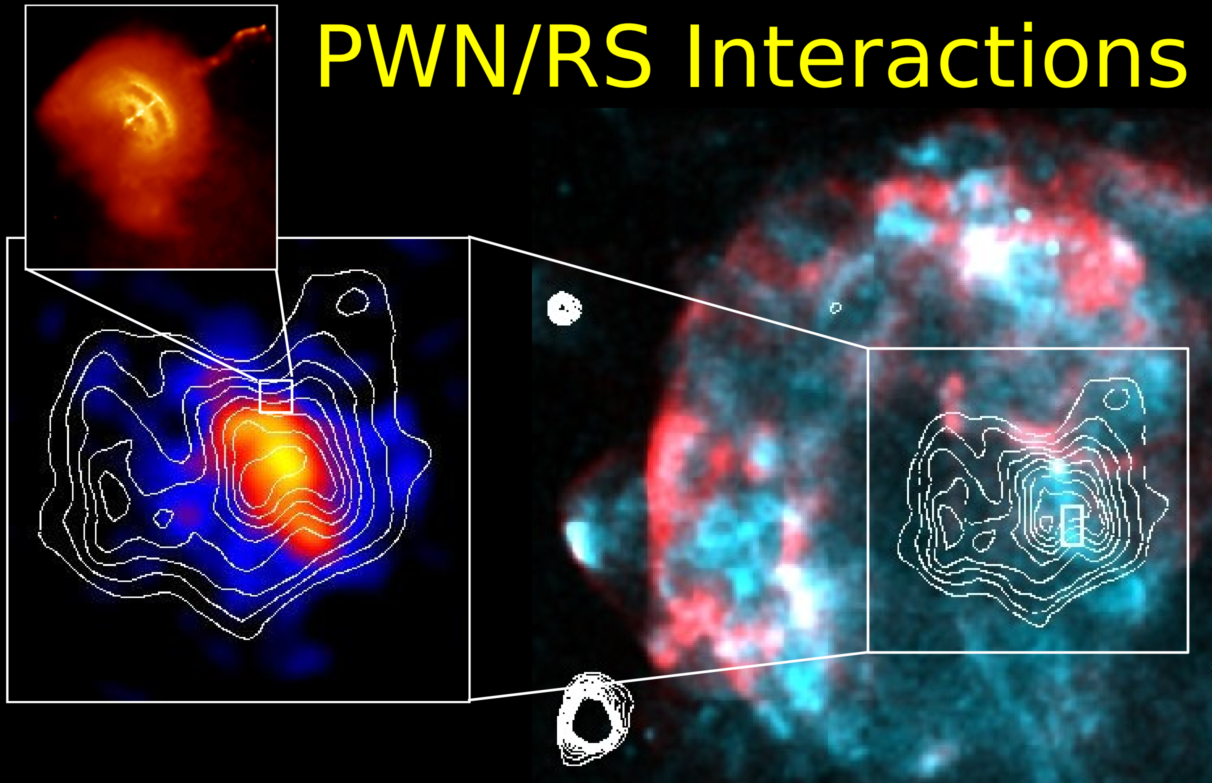
PWN Expansion w/ IXO: 3C 58

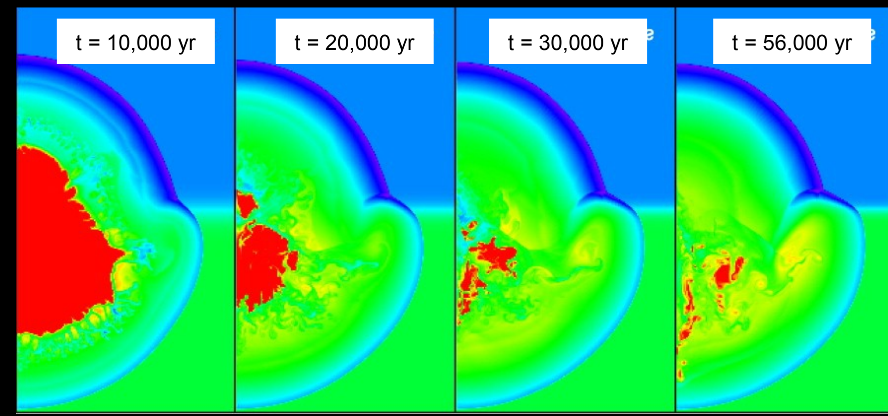




- Measure velocity broadening to determine age based on size
  - connect with evolution to determine initial spin and spindown properties
- Maximum velocities in optical are 900 km s^{-1}
  - to detect broadening we need resolution of about 2.7 eV

PWN/RS Interactions w/ IXO: Vela X



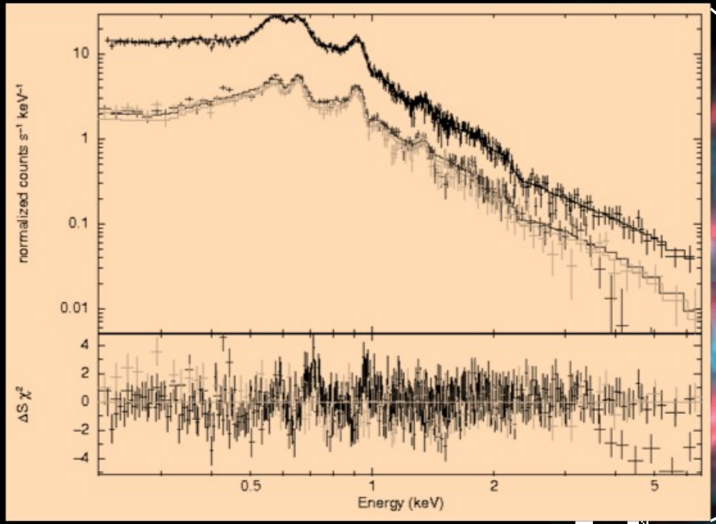


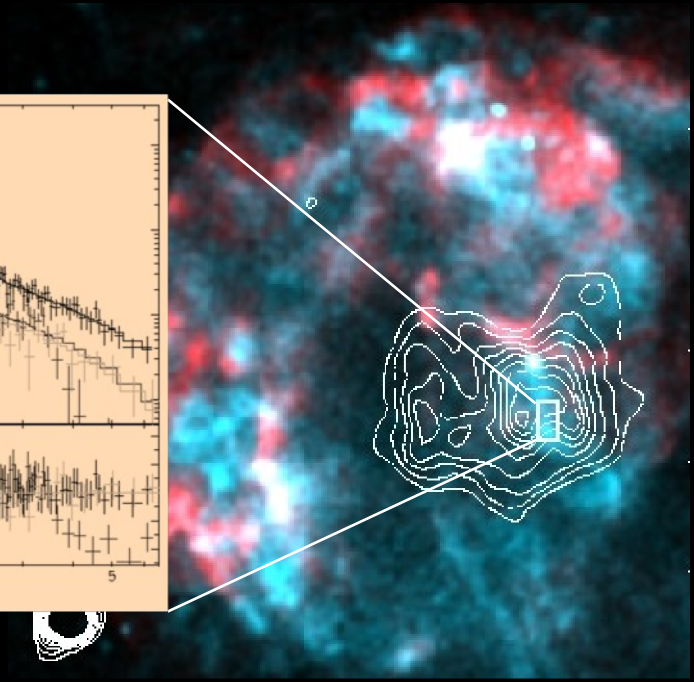
Blondin et al. 2001

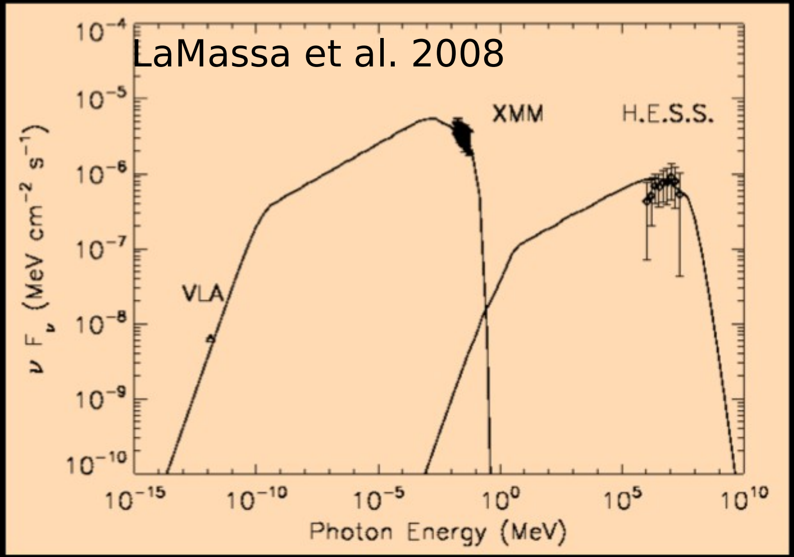
- Vela X is the PWN produced by the Vela pulsar
  - located primarily south of pulsar
  - apparently the result of relic PWN being disturbed by asymmetric passage of the SNR reverse shock

- Elongated "cocoon-like" hard X-ray structure extends southward of pulsar
  - clearly identified by HESS as an extended VHE structure
  - this is not the pulsar jet (which is known to be directed to NW); presumably the result of reverse shock interaction

PWN/RS Interactions w/ IXO: Vela X



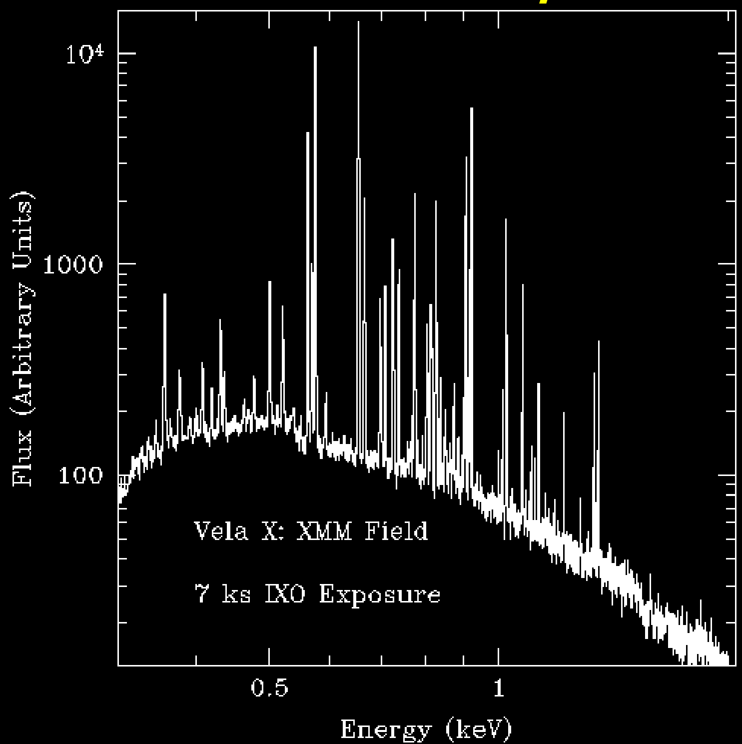


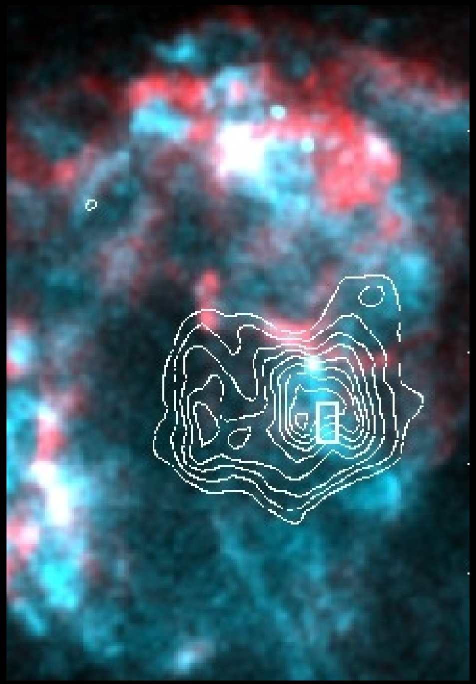


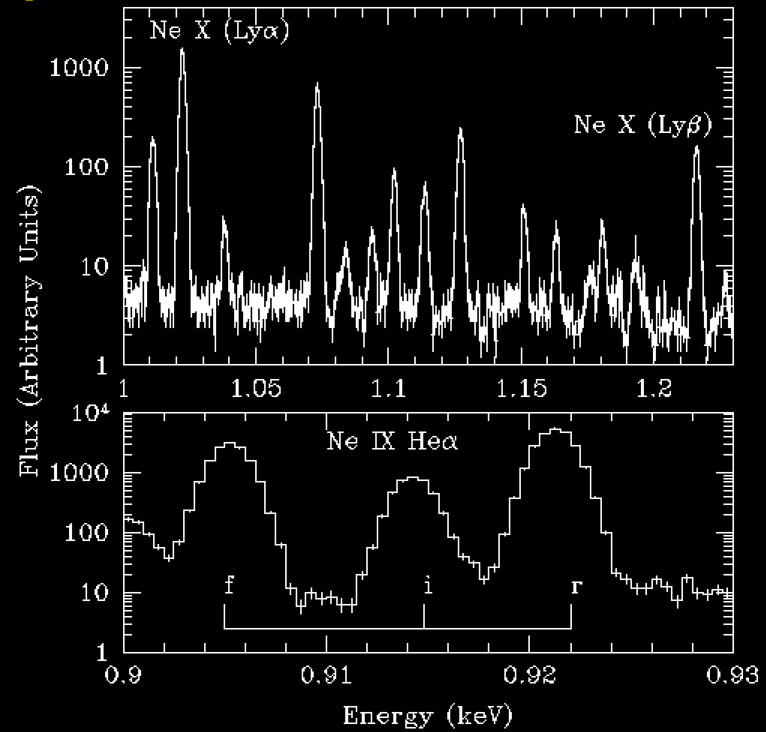
MM spectrum shows nonthermal <u>and</u> ejecta-rich thermal emission from cocoon
everse-shock crushed PWN and mixed in ejecta?

adio, X-ray, and γ -ray measurements appear consistent with synchrotron and I-C
nission from power law particle spectrum w/ two spectral breaks
ensity derived from thermal emission 10x lower than needed for pion-production to
rovide observed γ -ray flux
<u>nuch larger X-ray coverage of Vela X is required to fully understand structure</u>

PWN/RS Interactions w/ IXO: Vela X



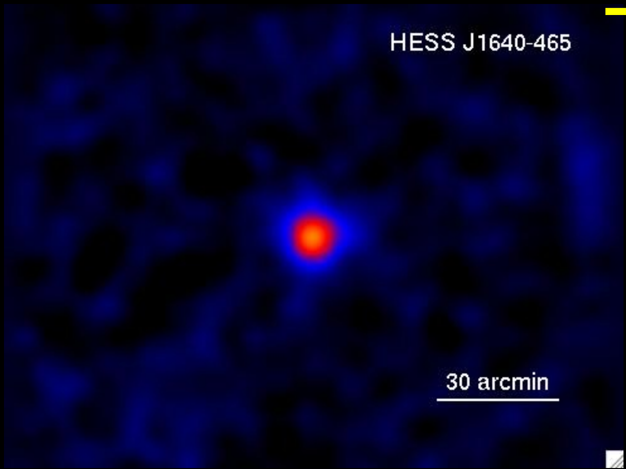


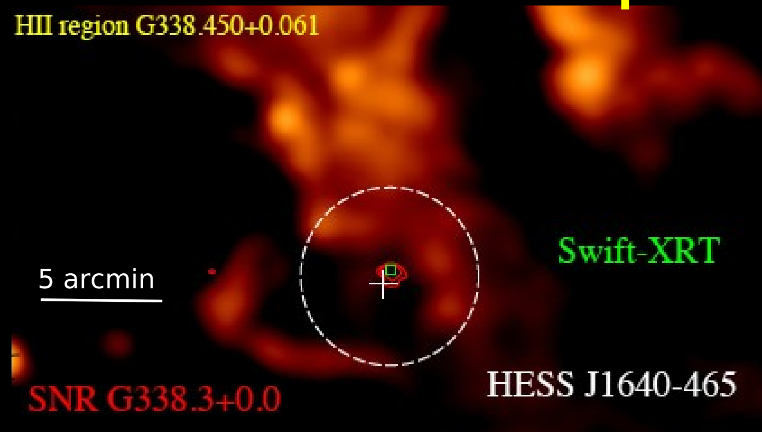


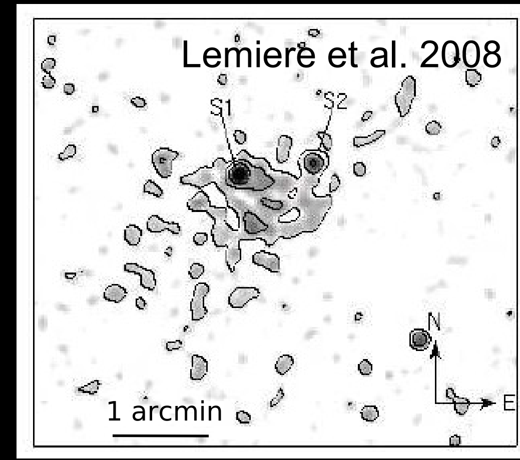
hermal properties of ejecta in/around Vela X constrain the PWN/RS interaction
expect additional compression and heating as RS meets PWN

XO will easily determine plasma parameters (temperature, density, abundances,
nd ionization state) in short exposures (e.g. Lyβ /Lyα ➔ kT, Heα [F]/[R] ➔ $n_e t$)
ine diagnostics will trace evolution of ejecta mixed into Vela X
similar studies will be enabled for other (much fainter) known systems of this type

TeV PWN Counterparts

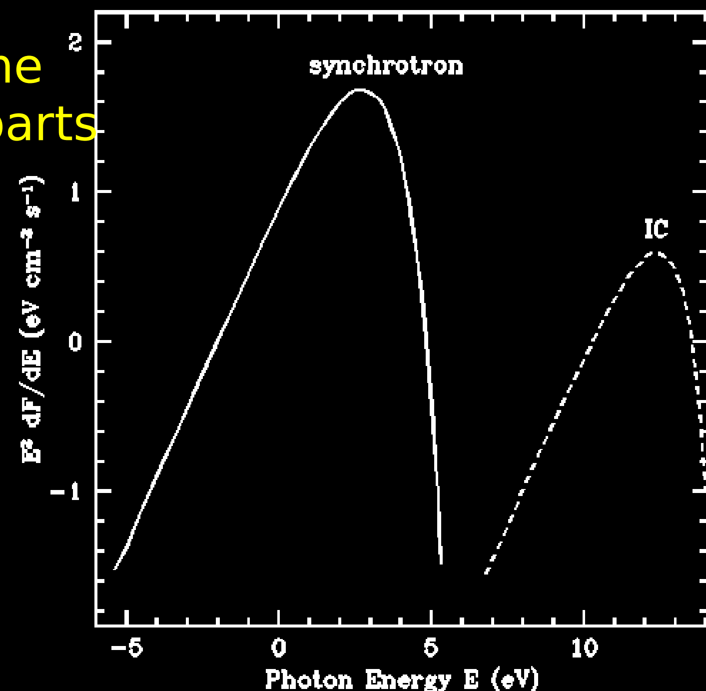






Nearly half of the detected TeV sources are thought to be PWNe
- no known pulsars associated with most sources
- X-ray observations reveal faint, extended nebulae for some
- large FOV and collecting area needed to identify counterparts
  ➔ ideal for IXO in relatively short (~10-100 ks) exposures

Large TeV/X-ray size ratio suggests low magnetic field systems, perhaps post-RS PWNe
- sensitive observations required to establish counterparts, and to produce X-ray flux and spectral maps
- magnetic field related to flux ratio



Impacts on IXO Design Requirements

- High throughput and spectral resolution will allow us to detect the thermal gas at very faint levels, even in the presence of synchrotron emission

- Line ratios will give temperature; modeling leads to density

  - constrain CSM ➔ progenitor properties

- Velocity broadening gives expansion velocity

  - Issues:

    field of view – prominent sources are 5 arcmin or more in size
    (may not be a problem with mosaic pointings)
    angular resolution – need to resolve small structure in PWNe
    effective area – thermal emission is faint; require large areas
    spectral resolution – need to detect velocities of < 1000 km s^{-1}